# SPLIT COAXIAL RFQ LINAC WITH MODULATED VANE

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## ABSTRACT

A new type split coaxial RFQ structure with modulated vanes is developed for a very heavy ion RFQ linac which can accelerate ions with charge to mass ratio more than 1/60 from 1.68 keV/u to 45 keV/u at frequency of 12.5 MHz. This structure is reduced to a scale of 1/4 the very heavy ion RFQ linac and is operated at 50 MHz. The structure consists of four cavity modules divided by three stems supporting horizontal and vertical vanes periodically and alternately. The structure is 2 m in length and 0.4 m in diameter.

## INTRODUCTION

A split coaxial ( S.C. ) RFQ linac operated at frequency of 50 MHz is in course of development at Institute for Nuclear Study ( INS ) in order to construct the very heavy ion RFQ linac. While the operating frequency is required to be as low as 12.5 MHz in the case of acceleration of uranium ions of energy as low as a few keV/u , it is expected that the basic and technical problems in the S.C. RFQ accelerating structure can be solved by the fablication and tests of 50 MHz structure.

In order to reduce the tank diameter of very heavy ion accelerating structure, S.C. RFQ structures have been proposed and developed at GSI [1], Frankfurt [2], Argonne [3] and so on. Compared with these RFQ structures, the structure developed at INS has a following feature: In the S.C. RFQ structure proposed and developed so far, the opposite electrodes are fixed and electrically grounded at one end of cavity and other opposite electrodes are fixed and grounded at other end of cavity. That is, all electrodes are supported at only one point. On the other hand, in INS type structure, all electrodes are supported at several points by adopting the multi-module cavity structure [4].

In the present work, the modulated vane is to be fabricated as a structure of electrode for the reason that the accelerating and quadrupole fields produced by the electrode are expressed exactly by a simple formula [5] and that effective use of our experience in a four vane type RFQ linac " LITL " construction is made.

The main purpose of this developement is to verify whether good mechanical stability and ease of the vane setting are obtained by supporting the modulated vanes at several points and whether voltage flattness along the beam axis is satisfactry. Furthermore, that is to establish accelerator techniques to be able to construct S.C. RFQ linac of 12.5 MHz at the next step.

## SPLIT COAXIAL RESONANT CAVITY

Schematic diagram of the split coaxial resonant cavity is shown in Fig. 1. This resonator is considered to be a modification of the re-entrant cavity of TEM mode. By spliting electrodes and by setting each splited electrode into each split, constant voltage is produced between adjacent electrodes. The potential difference between the electrode and the outer conductor of cavity is shown in Fig. 1.

The general merits of S.C. cavity are summarized as follows: 1) The diameter of the tank becomes small. 2) There is no deflection mode near the fundamental mode . 3) Voltage flatness along the beam axis is inherent without tuning. However, the high capacitance between electrodes is of advantage with respect to decreasing the resonant frequency but is of disadvantage with respect to increasing the rf power loss.

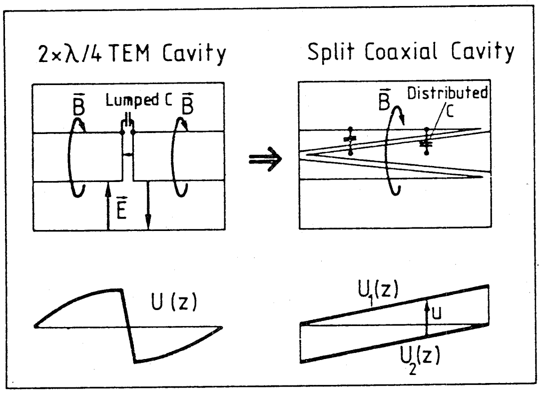


Fig. 1. Principle of the split coaxial resonant cavity.

## BEAM DYNAMICS DESIGN

Supposing to inject the beam into synchrotron, a profile of vane has been designed. Since the beam is not required to be so intensive, $^{238}U^{4+}$ has been chosen as a heaviest ion to be accelerated.

Table 1

RFQ Parameters of $^{238}U^{4+}$ RFQ and Its 1/4-Scaled Machine

| | $^{238}U^{4+}$ | 1/4-Scale | |
|---|---|---|---|
| Charge to mass ratio | 0.01681 | 0.06723 | |
| Frequency ($f$) | 12.5 | 50 | MHz |
| Kinetic energy ($T$) | 1.68 → 45 | 1.68 → 45 | keV/u |
| Normalized emittance ($\varepsilon_N$) | 0.06 | 0.015 | $\pi$ cm · mrad |
| Kilpatrick factor | 1.8 | 1.295 | |
| Intervane voltage ($V$) | 164.6 | 41.1 | kV |
| Focusing strength ($B$) | 4.5 | 4.5 | |
| Max. defocusing strength ($\Delta_b$) | −0.100 | −0.100 | |
| Synchronous phase ($\phi_s$) | −90 → −30 | −90 → −30 | deg |
| Max. modulation ($m_{max}$) | 1.83 | 1.83 | |
| Number of cells | 180 | 180 | |
| Vane length | 800 | 200 | cm |
| Mean bore radius ($r_0$) | 1.941 | 0.485 | cm |
| Min. bore radius ($a_{min}$) | 1.349 | 0.337 | cm |
| Margin of bore radius ($a_{min}/a_{beam}$) | 2.0 | 2.0 | |
| Transmission (0 $emA$) | 98 | 97 | % |
| (5 $emA$) | 97 | 73 | % |
| (10 $emA$) | 94 | | % |
| Module length | 200 | 49.4 | cm |
| Radius of cavity | 80 | 20 | cm |
| Ave. radius of inner conductor | 20 | 5 | cm |
| Electrode capacitance | 150 | 150 | pF/m |
| Rosonant resistance per module | 209 | 209 | kΩ |
| Unloaded Q value | 4850 | 4850 | |
| rf power per module | 65 | 4.0 | kW |
| Number of Modules | 4 | 4 | |
| Total power | 260 | 16.2 | kW |

The injection energy from ion source into RFQ is suppressed as low as possible in order to make use of the merit of RFQ linac sufficiently.

Output energy of 45 keV/u has been determined from the condition that the field gradient of focusing quadrupole magnet which is used in the drift tube linac of next stage, is 10 kG/cm at maximum. Vane length of 8 m is based on the tank design of the multi-module cavity structure. By fixing the output energy and the vane length as above, vane parameters have been searched so as to increase the output beam current as much as possible. Two computer codes GENRFQ and PARMTEQ have been used to determine the vane parameters.

In the design of radial matching section, it has to be considered that the potential on beam axis is not zero but one half of the potential difference between electrodes. In order to obtain the required quadrupole field, the geometrical arrangement of the four vanes in the transversal cross section is asymmetric with respect to the beam axis. The length of radial matching section is chosen so that the acceleration of particles is negligible on all phases.

The design parameters of the 12.5 MHz RFQ structure for $^{238}U^{4+}$ acceleration are compared with that of the 50 MHz RFQ structure in Table 1. The 50 MHz RFQ structure can accelerate ions with the charge to mass ratio more than 1/15. In the case of proton acceleration, rf power of about 40 W is sufficient.

## MULTI-MODULE CAVITY STRUCTURE

A fundamental diagram of the multi-module cavity structure is shown in Fig. 2. The cavity consists of cavity modules divided by two stems. One module corresponds to one resonant cavity. Horizontal and vertical vanes are suppoted by the vertical and horizontal stems every one module periodically and alternately. In the case of four-module cavity, horizontal and vertical vanes are supported at two or three points, respectively.

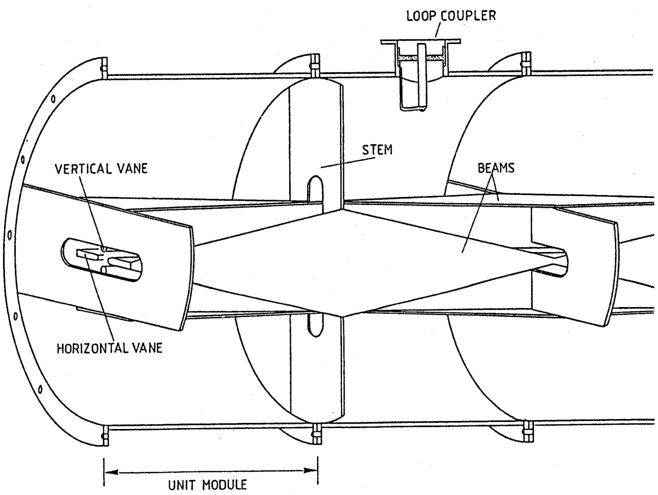


Fig. 2. Illustration of multi-module cavity structure.

Since each module is coupled by the vanes and stems with each other, the cavity is excited in a $\pi$-mode where the phase of field changes every one module by $\pi$ . In this structure, diamond-shaped plate beams ( triangular plate beams in both end modules ) are used in order to improve the voltage flatness along the beam axis and in order to strengthen the support of vanes. Since the shape of the beam is simple, the manufacturing and assembling of electrodes are also easy.

The length and diameter of each module are determined by compromizing with following demands: to obtain the higher resonant resistance, $R_p$, for decreasing the rf power loss, to make short the interval between the supporting points of vanes for getting the mechanical stability and to make small the radius of cavity for decreasing construction cost. The relation between the cavity radius, $r_b$, and the module length, L, is obtained by determining the electrode capacitance, C, the radius of inner conductor, $r_a$, and the stem width, W.

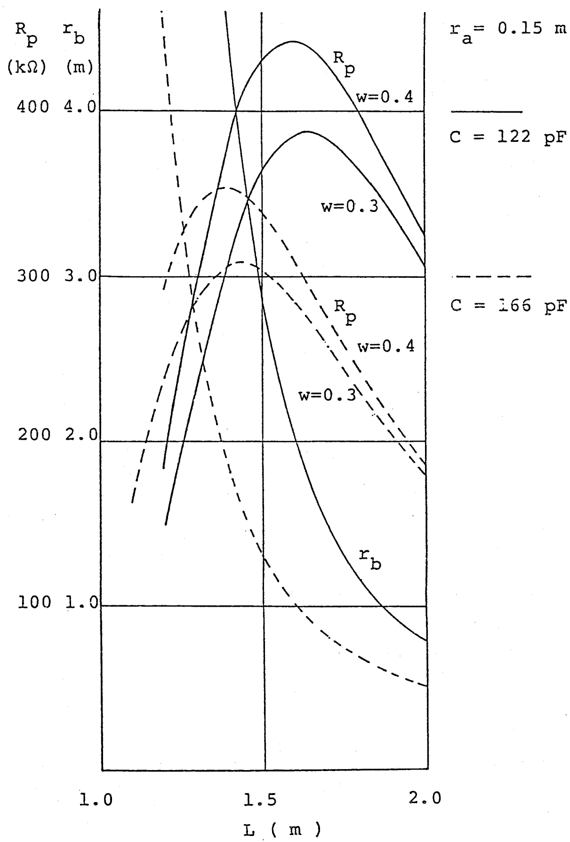


Fig. 3. The relations of cavity parameters.

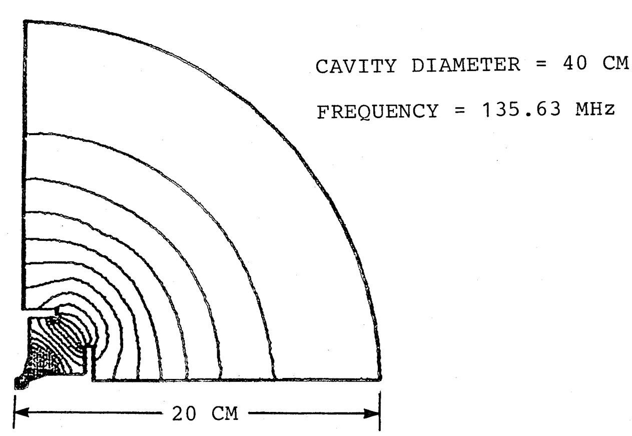


Fig. 4. Cross section of the four vane cavity.

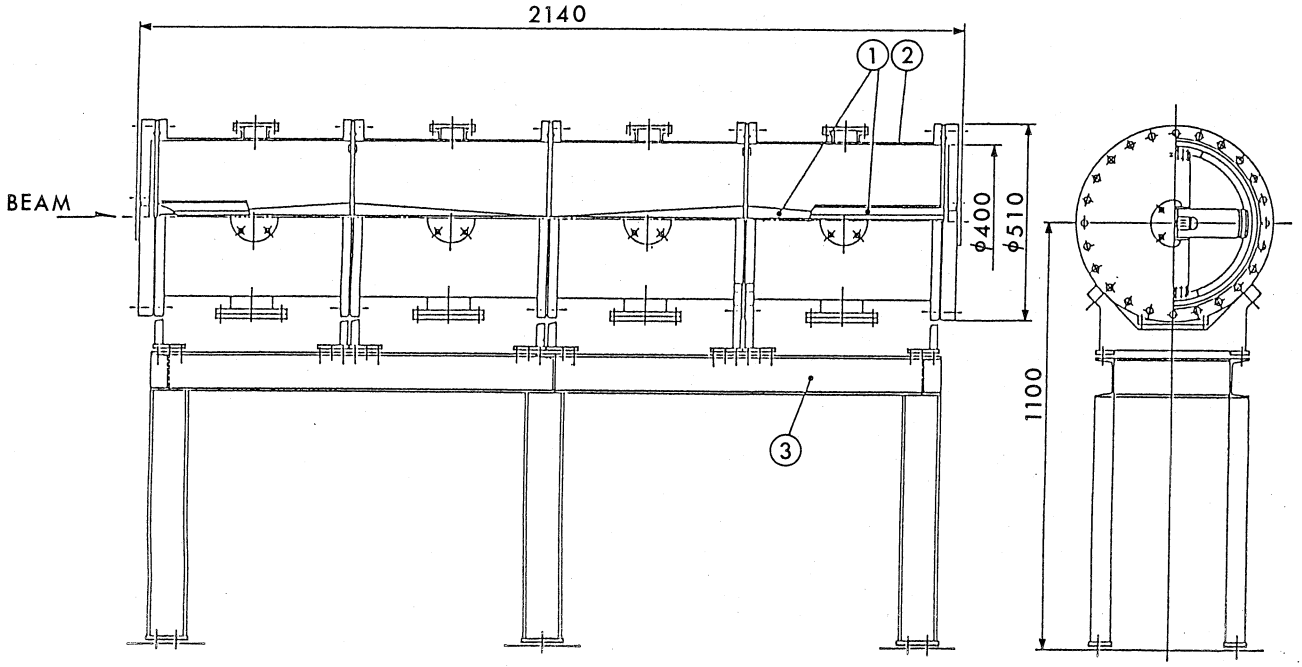


Fig. 5. 50MHz S.C. RFQ cavity structure.

In order to examine the contribution of the electrode capacitance and stem width to the length and diameter of a module, the relations are given in Fig. 3 assuming the capacitance, the width and the radius of inner conductor appropriately. The electrode capacitance has been obtained by using the computer code SUPERFISH. The capacitance is derived from the resonant frequency of a four vane cavity as shown in Fig. 4 assuming that the density of magnetic flux is constant. Dimensions of the 12.5 MHz and 50 MHz cavities are given in Table 1.

A multi-module cavity structure of 50 MHz is shown in Fig. 5. All parts of the cavity are made from brass since that is cheap and comfortable to machine. In the low power test for examining the rf characteristics, vanes from brass have not modulation. In the step of acceleration test, modulated vanes are made from copper. The resonant frequency of each module is adjusted with a loop tuner.

This 50 MHz RFQ structure is manufactured at machine shop of INS. Vane disign has been carried out with the computer M180-II-AD of the INS computer facility.

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